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Temporal development of salt marsh value for nekton and epifauna: utilization of dredged material marshes in Galveston Bay, Texas, USA

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Abstract

Densities of nekton and other fauna were measured in three created salt marshes to examine habitat development rate. All three marshes were located on Pelican Spit in Galveston Bay, Texas, USA and were created on dredged material from the Gulf Intracoastal Waterway. The youngest marsh was planted on 1-m centers in July of 1992. At the time sampling was initiated in fall 1992, the marshes were 9, 5, and less than 1 year in age; sampling continued in the fall and spring through spring 1994. Animal densities were measured within the vegetation at two elevations using an enclosure sampler. In the fall of 1992, 4 months following the planting of the 92Marsh, densities of most marsh organisms were lower in this marsh compared with the older two marshes. Significantly lower densities were observed for dominant crustaceans (including three species of grass shrimps, two species of commercially-important penaeid shrimps, thinstripe hermit crabs *Clibanarius vittatus*, and juvenile blue crabs *Callinectes sapidus*), a dominant fish (*Gobionellus boleosoma*), and the dominant mollusc (*Littoraria irrorata*). By the fall of 1993, however, densities of most nekton species were similar among the three created salt marshes. In contrast, reduced densities of less mobile epifauna (*C. vittatus* and *L. irrorata*) persisted in the 92Marsh throughout the 2 years of sampling. The patterns of nekton utilization exhibited in these marshes suggest that the 92Marsh reached its maximum habitat support function for these animals in less than 1 year. Comparisons of the older marshes with natural marshes in the bay system, however, suggest that all three of these created marshes are functioning at lower levels than natural marshes in terms of supporting production of commercially important fishery species such as penaeid shrimps and *C. sapidus*.

Introduction

Salt marshes in the northern Gulf of Mexico support high densities of decapod crustaceans and small fishes (Zimmerman and Minello, 1984; Rozas and Reed, 1993; Peterson and Turner, 1994; Minello, 1999), and for some estuarine nekton, marshes have been shown to provide food for growth and shelter for increased survival (Boesch and Turner, 1984; Minello et al., 1989; Stunz, 1999; Zimmerman et al., 2000). Extensive losses of wetlands in the northern Gulf have encouraged marsh restoration efforts, and many marshes are being created on dredged material. However, there is still controversy over whether created marshes function like natural salt marshes for estuarine animals (Race and Christie, 1982; Moy and Levin, 1991; Levin et al., 1996; Zedler, 1996; Zedler et al., 1997; Dionne et al., 1999). During early years of development, created marshes in the northern Gulf of Mexico do not appear to support comparable densities of some fishes and crustaceans when compared with natural marshes (Minello and Zimmerman, 1992; Minello and Webb, 1997). However, estimating development time or the relationship between marsh age and nekton use from studies of different-aged marshes is complicated by other differences among marshes (such as geographic location and marsh surface elevation) that may also affect animal use.

The objective of this study was to examine temporal development of habitat functions in dredged

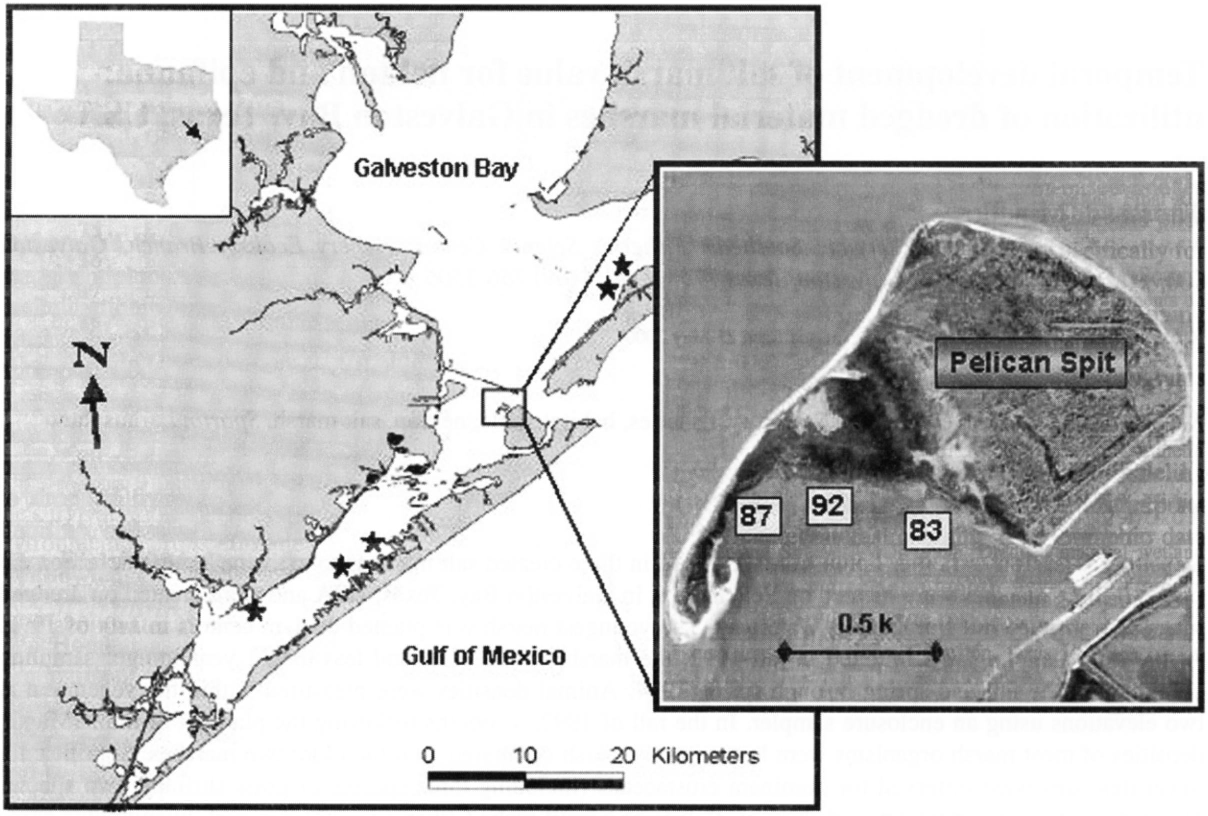


Figure 1. Location of the three created salt marshes (83Marsh, 87Marsh, 92Marsh) on Pelican Spit in Galveston Bay, Texas (29° 21′ N, 94° 49′ W). Stars indicate locations of natural marshes used for comparison (Minello and Webb, 1997).

material salt marshes of Galveston Bay by comparing nekton use patterns in three created marshes of different ages. To minimize effects of location and elevation, I selected three marshes that were located within a 60-hectare area (Figure 1) and sampled at the same surface elevation in each marsh. I assumed that animal densities on the marsh surface were an indicator of functional value, measured densities of nekton and other fauna using an enclosure device (Zimmerman et al., 1984; Rozas and Minello, 1997), and tested the null hypothesis that nekton use was similar among the marshes regardless of their age.

Methods

All three marshes were created on sediment that was hydraulically dredged during maintenance of the Gulf Intracoastal Waterway and deposited on Pelican Spit in Galveston Bay (Figure 1). Before 1983, *Spartina alterniflora* occurred along the shoreline of Pelican Spit. An unplanned deposit of dredged material in 1983 covered much of this marsh, and this dredged material revegetated naturally. Aerial photographs document the reestablishment of vegetation in the marsh by 1985. Herein, this area of the island is termed the 83Marsh (Figure 1). The other marshes were transplanted on newly-deposited sediment in 1987 (87Marsh) and in the summer of 1992 (92Marsh) as part of a cooperative Memorandum of Agreement between the National Marine Fisheries Service and the U.S. Army Corps of Engineers. Dredged material for the youngest marsh was deposited in January 1992, and planting of the marsh was completed by early July of the same year. Both the 87Marsh and 92Marsh were planted with *S. alterniflora* sprigs on 1-m centers; donor plants were taken from inland areas of the 83Marsh. The 83Marsh and the 87Marsh have been studied previously and were named T5 and T4, respectively, in Minello and Webb (1997).

Animal densities on the marsh surface were measured in the fall and spring, during the first 2 years following planting of the 92Marsh. These seasons were chosen because large numbers of young pen-

Figure 2. Drop sampler used to collect nekton in a salt marsh.

aeid shrimps, blue crabs, and estuarine fishes recruit into the Galveston Bay system at these times and are present in natural marshes. Sampling of the three marshes began about 4 months after the 92Marsh was planted; at this time (fall 1992), the marshes were 9, 5, and less than 1 year in age.

Enclosure samplers can provide estimates of nekton density at specific locations within the marsh vegetation. In each marsh, four replicate enclosure samples were collected at each of two marsh surface elevations, because elevation appears to be important in determining nekton use of intertidal habitats (Rozas and Reed, 1993; Minello and Webb, 1997). Water depth at slack high tide was used to measure relative marsh elevations. The marsh edge (vegetation-water interface) occurred at similar elevations in the three marshes, and the low-elevation or edge samples were collected within the marsh vegetation, 1–2 m from the marsh edge. Inner marsh samples were collected at an elevation 20 cm higher than edge samples. Marsh slopes varied, and the inner marsh samples were taken at approximately 3 m from the marsh edge in the 83Marsh, 5 m from the edge in the 87Marsh, and 75 m from the edge in the 92Marsh. A total of 24 drop samples was collected during each sampling period including the fall of 1992 (October 19–20), spring of 1993 (May 21–25), fall of 1993 (Sept 30-Oct 1), and spring of 1994 (May 19–20).

Sampling of animal densities followed methods developed by Zimmerman et al. (1984). This technique employs a large cylinder (1.8-m diameter) that is dropped from a boom on a boat to entrap organisms within a 2.6-m^2 area of marsh (Figure 2). Sampling was conducted during the day at high tide when marshes were flooded. After the sampler was in place, water depth, temperature, dissolved oxygen, salinity, and turbidity were measured within the enclosure. To reduce impact on the marshes, *S. alterniflora* was generally not clipped and removed from the sampler. However, during the spring of 1993, vegetation was clipped at the substrate surface from a 0.25-m^2 quadrat placed in the center of the sampler for determination of stem density. Most of the natant macrofauna trapped in the sampler were removed using dip nets while the water was pumped out of the enclosure and through a 1-mm mesh net. When the sampler was completely drained, animals remaining on the bottom were picked up by hand. The collection was preserved in formalin with Rose Bengal stain. In the laboratory, fishes, crustaceans, and molluscs were identified to species and counted.

Density values were analyzed with analysis of variance (ANOVA) following a ln+1 transformation required to remove the positive relationship between cell means and standard deviations in the raw data. For each sampling period, a 2-way factorial ANOVA was conducted on densities of abundant taxa; similar analyses were used to look for significant differences in physical variables (untransformed) among the marshes. The factors in the ANOVA included Marsh (83Marsh, 87Marsh, 92Marsh) and Elevation (low or high). *A priori* contrasts were calculated within the main effect of Marsh to compare mean densities between the 92Marsh and each of the older marshes. Probability values < 0.05 were considered significant.

The three marshes at Pelican Spit were all created on dredged material, and no natural reference marshes are present in the immediate area. However, in a previous study of the Galveston Bay system (Minello and Webb, 1997), the 83Marsh and 87Marsh were included in a comparison of animal densities among natural and created marshes. Data from this study have been presented on the density figures to provide a comparison of animal densities in the Pelican Spit marshes with natural marsh habitats.

Results

A total of 27,516 organisms was collected in the drop samples over the four sampling periods, and crustaceans made up about 85% of the fauna (Table 1). Twenty-four crustacean species were identified, but three species of grass shrimp (*Palaemonetes pugio*, *P. intermedius*, and *P. vulgaris*) dominated, making up 81% of the crustaceans. Juveniles of the commercially-important shrimps *Farfantepenaeus aztecus* (formerly *Penaeus aztecus*, Perez-Farfante and Kensley 1997) and *Litopenaeus setiferus* (formerly *Penaeus setiferus*, Perez-Farfante and Kensley 1997) were also abundant and together made up 10% of the crustaceans. Fishes made up only around 7% of the animals sampled, but diversity was high, and 41 species were identified (Table 1). Fishes were dominated by juvenile white mullet *Mugil curema* (collected mainly in the spring of 1993), darter goby *Gobionellus boleosoma*, and bay anchovy *Anchoa mitchilli*. Molluscs made up about 9% of the fauna sampled, and almost all were marsh periwinkles *Littoraria irrorata*.

Water salinity, temperature, dissolved oxygen, and turbidity did not vary greatly among the marshes or between elevations. There were significant differences among the marshes in temperature during the fall of 1992 and spring of 1994; values among the three marshes ranged from 21.8 to 23.8 °C and 25.6 to 27.9 °C, respectively. Within marshes, however, nekton densities were not strongly related to water temperature. An analysis of covariance, with temperature as the covariate and the same main effects as in the ANOVAs, indicated that temperature did not explain any significant variability in densities of nekton. Salinity also varied significantly among the marshes in spring (marsh means ranged from 8.9 to 11.6 ppt) and fall (25.6 to 26.6 ppt) of 1993, but these differences were small and unlikely to be of any biological significance. Mean stem density of *S. alterniflora* during the spring of 1993 was highest in the 87Marsh (high-elevation inner mean = 342 stems/m^2, SE = 20.9; low-elevation

Table 1. Mean densities (number per 2.6-m^2 drop sample) and standard errors (SE) of nekton and other animals collected in 32 samples from each of the three created marshes on Pelican Spit over the 2-year sampling period (Fall 1992 through Spring 1994). Species are ranked within major taxonomic categories based on overall abundance.

Species	Common name	83Marsh		87Marsh		92Marsh	
		Mean	(SE)	Mean	(SE)	Mean	(SE)
Crustaceans		**269.97**	**(55.35)**	**331.38**	**(75.89)**	**126.13**	**(19.26)**
Palaemonetes pugio	daggerblade grass shrimp	113.34	(14.73)	201.44	(42.43)	81.00	(15.25)
Palaemonetes intermedius	brackish grass shrimp	76.91	(35.22)	41.00	(19.10)	10.50	(3.20)
Palaemonetes vulgaris	marsh grass shrimp	23.38	(10.21)	34.16	(19.32)	4.97	(2.48)
Farfantepenaeus aztecus	brown shrimp	18.13	(3.16)	13.16	(2.58)	14.06	(2.32)
Litopenaeus setiferus	white shrimp	11.69	(6.07)	14.59	(7.32)	2.75	(0.74)
Clibanarius vittatus	thinstripe hermit	10.28	(1.74)	14.19	(2.53)	0.94	(0.28)
Callinectes sapidus	blue crab	7.38	(1.19)	7.88	(1.25)	5.47	(1.18)
Palaemonetes spp. (postlarval)		4.44	(3.46)	0.72	(0.38)	4.25	(3.02)
Callinectes similis	lesser blue crab	2.03	(0.63)	0.25	(0.17)	0.69	(0.26)
Sesarma cinereum	squareback marsh crab	1.34	(0.38)	0.81	(0.41)	0.13	(0.07)
Uca spp.		0.00	(0.00)	1.81	(1.00)	0.41	(0.24)
Farfantepenaeus duorarum	pink shrimp	0.00	(0.00)	0.66	(0.62)	0.22	(0.22)
Sesarma reticulatum	heavy marsh crab	0.16	(0.13)	0.41	(0.30)	0.00	(0.00)
Leander tenuicornis	brown grass shrimp	0.00	(0.00)	0.09	(0.09)	0.38	(0.25)
Dsypanopeus texana	gulf grassflat crab	0.06	(0.06)	0.00	(0.00)	0.19	(0.16)
Latreutes parvulus	sargassum shrimp	0.09	(0.09)	0.00	(0.00)	0.06	(0.06)
Panopeus herbstii	Atlantic mud crab	0.03	(0.03)	0.06	(0.04)	0.03	(0.03)
Rhithropanopeus harrisii	Harris mud crab	0.03	(0.03)	0.00	(0.00)	0.03	(0.03)
Menippe adina	gulf stone crab	0.00	(0.00)	0.00	(0.00)	0.03	(0.03)
Eurypanopeus depressus	flatback mud crab	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Panopeus turgidus	ridgeback mud crab	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Pachygrapsus gracilis	dark shore crab	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Sesarma sp.		0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Trachypenaeus sp.		0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Fishes		**25.03**	**(5.41)**	**15.16**	**(3.43)**	**17.31**	**(2.71)**
Mugil curema	white mullet	9.81	(5.15)	3.63	(2.64)	3.38	(1.48)
Gobionellus boleosoma	darter goby	5.66	(0.83)	4.69	(0.91)	3.03	(0.57)
Anchoa mitchilli	bay anchovy	0.03	(0.03)	0.31	(0.31)	5.53	(2.34)
Mugil cephalus	striped mullet	2.34	(1.63)	1.25	(0.58)	0.47	(0.22)
Lagodon rhomboides	pinfish	1.03	(0.31)	1.69	(0.49)	1.31	(0.44)
Symphurus plagiusa	blackcheek tonguefish	1.19	(0.37)	0.50	(0.13)	0.84	(0.23)
Menidia beryllina	inland silverside	0.94	(0.52)	0.19	(0.19)	0.28	(0.14)
Citharichthys spilopterus	bay whiff	0.22	(0.07)	0.56	(0.25)	0.38	(0.16)
Brevoortia patronus	gulf menhaden	0.81	(0.55)	0.00	(0.00)	0.13	(0.13)
Fundulus similis	longnose killifish	0.69	(0.33)	0.13	(0.10)	0.13	(0.06)
Anchoa hepsetus	striped anchovy	0.81	(0.81)	0.00	(0.00)	0.00	(0.00)
Fundulus grandis	gulf killifish	0.28	(0.12)	0.38	(0.16)	0.06	(0.04)
Gobiesox strumosus	skilletfish	0.09	(0.07)	0.47	(0.17)	0.06	(0.04)
Chaetodipterus faber	Atlantic spadefish	0.00	(0.00)	0.06	(0.04)	0.41	(0.24)
Leiostomus xanthurus	spot	0.09	(0.07)	0.03	(0.03)	0.31	(0.15)
Gobiosoma robustum	code goby	0.09	(0.07)	0.00	(0.00)	0.34	(0.20)
Gobiosoma bosc	naked goby	0.00	(0.00)	0.34	(0.31)	0.00	(0.00)
Pogonias cromis	black drum	0.31	(0.18)	0.03	(0.03)	0.00	(0.00)
Sciaenops ocellatus	red drum	0.03	(0.03)	0.09	(0.05)	0.03	(0.03)
Eucinostomus spp.		0.03	(0.03)	0.09	(0.05)	0.03	(0.03)
Harengula jaguana	scaled sardine	0.00	(0.00)	0.00	(0.00)	0.16	(0.16)
Micropogonias undulatus	Atlantic croaker	0.00	(0.00)	0.00	(0.00)	0.13	(0.10)

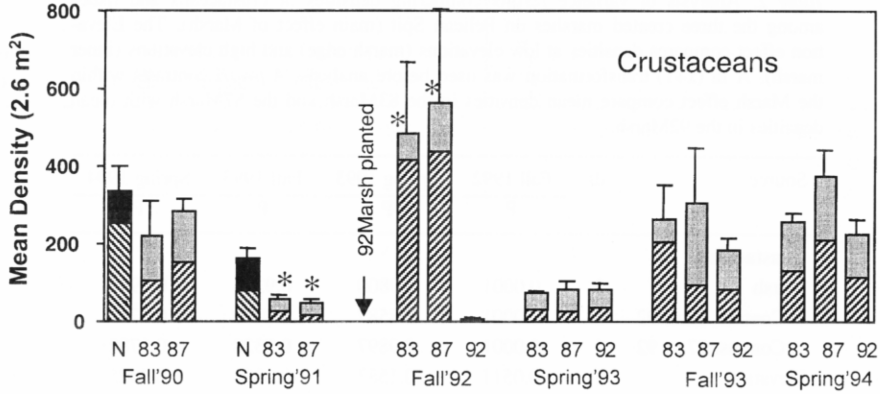
Table 1. Continued.

Species	Common name	83Marsh		87Marsh		92Marsh	
		Mean	(SE)	Mean	(SE)	Mean	(SE)
Syngnathus louisianae	chain pipefish	0.03	(0.03)	0.09	(0.05)	0.00	(0.00)
Eucinostomus argenteus	spotfin mojarra	0.03	(0.03)	0.09	(0.07)	0.00	(0.00)
Eucinostomus melanopterus	flagfin mojarra	0.09	(0.09)	0.00	(0.00)	0.03	(0.03)
Bairdiella chrysoura	silver perch	0.00	(0.00)	0.09	(0.07)	0.00	(0.00)
Myrophis punctatus	speckled worm eel	0.00	(0.00)	0.06	(0.04)	0.00	(0.00)
Synodus foetens	inshore lizardfish	0.03	(0.03)	0.00	(0.00)	0.03	(0.03)
Cynoscion nebulosus	spotted seatrout	0.03	(0.03)	0.03	(0.03)	0.00	(0.00)
Achirus lineatus	lined sole	0.03	(0.03)	0.03	(0.03)	0.00	(0.00)
Adinia xenica	diamond killifish	0.06	(0.04)	0.00	(0.00)	0.00	(0.00)
Cynoscion arenarius	sand seatrout	0.00	(0.00)	0.00	(0.00)	0.06	(0.06)
Lutjanus griseus	gray snapper	0.00	(0.00)	0.06	(0.04)	0.00	(0.00)
Paralichthys lethostigma	southern flounder	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Lucania parva	rainwater killifish	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Syngnathus scovelli	gulf pipefish	0.00	(0.00)	0.00	(0.00)	0.03	(0.03)
Fundulus pulvereus	bayou killifish	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Dasyatis sabina	Atlantic stingray	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Bathygobius soporator	frillfin goby	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Evorthodus lyricus	lyre goby	0.00	(0.00)	0.03	(0.03)	0.00	(0.00)
Caranx hippos	crevalle jack	0.00	(0.00)	0.00	(0.00)	0.03	(0.03)
Molluscs		**41.41**	**(8.32)**	**30.38**	**(5.31)**	**3.13**	**(1.29)**
Littoraria irrorata	marsh periwinkle	40.72	(8.38)	29.78	(5.30)	1.28	(0.44)
Tagelus spp.		0.47	(0.24)	0.09	(0.05)	1.41	(1.13)
Crepidula plana	eastern white slippersnail	0.03	(0.03)	0.41	(0.18)	0.00	(0.00)
Tellina texana	Say tellin	0.03	(0.03)	0.00	(0.00)	0.31	(0.18)
Crassostrea virginica	eastern oyster	0.03	(0.03)	0.03	(0.03)	0.09	(0.09)
Rangia cuneata	Atlantic rangia	0.00	(0.00)	0.06	(0.06)	0.00	(0.00)
Mulinia lateralis	dwarf surf clam	0.06	(0.04)	0.00	(0.00)	0.00	(0.00)
Cerithidea pliculosa	plicate hornsnail	0.03	(0.03)	0.00	(0.00)	0.00	(0.00)
Ensis minor	minor jackknife	0.03	(0.03)	0.00	(0.00)	0.00	(0.00)
Tellina spp.		0.00	(0.00)	0.00	(0.00)	0.03	(0.03)

edge mean = 155 stems/m^2, SE = 29.9), intermediate in the 83Marsh (high-elevation inner mean = 232 stems/m^2, SE = 33.7; low-elevation edge mean = 140 stems/m^2, SE = 30.2), and lowest in the 92Marsh (high-elevation inner mean = 147 stems/m^2, SE = 29.7; low-elevation edge mean = 82 stems/m^2, SE = 29.8).

During the first sampling period, four months after the 92Marsh was planted, crustacean densities in the 92Marsh were significantly lower (about 1%) than densities in the 83Marsh and 87Marsh (Figure 3, Table 2). During subsequent sampling periods, densities in the 92Marsh were not significantly different from the older marshes. Mean crustacean densities measured in fall 1990 and spring 1991 (before the creation of the 92Marsh) in the 83Marsh and 87Marsh were lower than in natural marshes, and these differences were significant in the spring of 1991 (Figure 3). Marsh surface elevation did not significantly affect overall crustacean densities (Table 2).

The daggerblade grass shrimp *Palaemonetes pugio* was the most abundant crustacean collected, and this species was absent from the 92Marsh during the first sampling period in fall 1992. By spring 1993, however, densities were not significantly different among the three created salt marshes, and this pattern continued through spring 1994 (Figure 4). The other abundant grass shrimps, *P. intermedius* and *P. vulgaris*, had



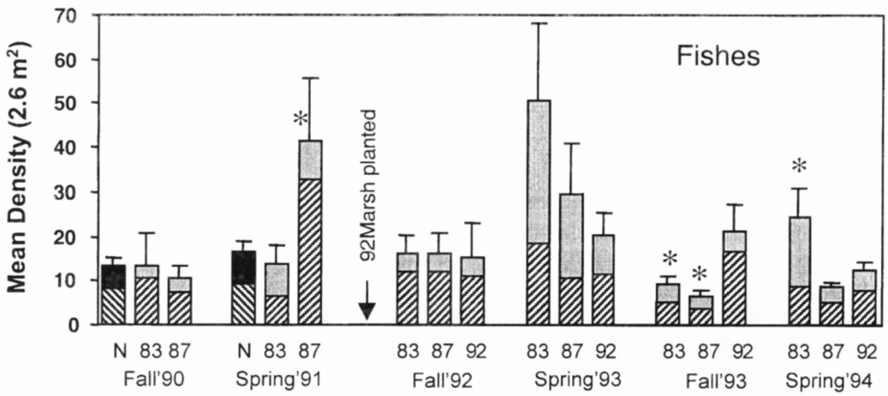


Figure 3. Bar heights represent mean densities (error bar is 1 SE) in marshes on Pelican Spit. The marshes are identified by the year in which they were constructed (1983, 1987, and 1992). The first two sampling periods occurred before the 92Marsh was constructed and are included for comparison with densities in five natural marshes (N) of the Galveston Bay system (see Minello and Webb, 1997 for details). Each bar is divided into two sections that represent the relative contribution of low-elevation edge (hatched) and high-elevation inner marsh habitats to the mean. An asterisk above the 83Marsh and 87Marsh bars notes a significant (0.05 level) difference from either natural marshes or the 92Marsh based on contrasts from within an ANOVA.

similar distribution patterns among the marshes, although these shrimps were virtually absent from any of the marshes in spring 1993 (Figure 4). Both of these grass shrimp species were also concentrated in the low-elevation edge marsh (the Elevation effect was significant in 3 of 6 ANOVAs) in contrast to the relatively even distribution between edge and inner marsh exhibited by *P. pugio*.

Densities of juvenile brown shrimp *Farfantepenaeus aztecus* and white shrimp *Litopenaeus setiferus* were significantly lower in the 92Marsh compared with the 83Marsh and 87Marsh during fall 1992 (Figure 5). For the remaining sampling periods, however, densities of these species were generally similar among the marshes. White shrimp did not occur again in substantial numbers until fall 1993, just over one year after the 92Marsh was created, and densities at this time were significantly higher in the 92Marsh than in the 83Marsh (Figure 5). Densities of blue crab *Callinectes sapidus* in the 92Marsh were significantly lower than in the other created marshes for two sampling periods following construction of the new marsh (Figure 5). By fall 1993, however, densities among all three marshes were similar. Within each marsh, highest mean densities of these commercially-important crustaceans occurred at the low-elevation marsh edge, and the ANOVA Elevation effect was significant in fall 1992 and spring 1994 for *F. aztecus* and in spring 1994 for *L. setiferus* and *C. sapidus*.

The thinstripe hermit crab *Clibanarius vittatus* was the only abundant crustacean species that exhibited consistently lower densities in the 92Marsh compared

Table 2. Analysis of variance results comparing densities of crustaceans and fishes among the three created marshes on Pelican Spit (main effect of Marsh). The Elevation effect compares densities at low elevations (marsh edge) and high elevations (inner marsh). A ln (x+1) transformation was used before analysis. *A priori* contrasts within the Marsh effect compare mean densities in the 83Marsh and the 87Marsh with mean densities in the 92Marsh.

Source	df	Fall 1992	Spring 1993	Fall 1993	Spring 1994
		P	P	P	P
Crustaceans					
Marsh	2	0.0001	0.9800	0.9384	0.3938
Contrast 83 vs 92	1	0.0001	0.8587	0.8070	0.4767
Contrast 87 vs 92	1	0.0001	0.9897	0.7328	0.1782
Elevation	1	0.0511	0.1583	0.6384	0.4425
Marsh*Elevation	2	0.1785	0.5158	0.0737	0.8370
Residual error	18				
Fishes					
Marsh	2	0.1394	0.2383	0.0043	0.0101
Contrast 83 vs 92	1	0.0851	0.0967	0.0214	0.0423
Contrast 87 vs 92	1	0.0865	0.4895	0.0013	0.2340
Elevation	1	0.0544	0.8609	0.0062	0.6035
Marsh*Elevation	2	0.9661	0.5614	0.2951	0.2426
Residual error	18				

with the older created marshes (Figure 6). Almost all individuals in the 92Marsh occurred at the low-elevation marsh edge, and this distributional pattern resulted in a significant interaction between Marsh and Elevation in the ANOVA for Fall 1993.

Densities of fishes as a group in the 92Marsh were not significantly different from densities in the older marshes during the first year following marsh creation (Figure 3, Table 2). Significant differences among the marshes occurred during the second year, but these differences did not appear related to the age of the newly created marsh. White mullet *Mugil curema* was the most abundant fish collected (Table 1), but temporal and spatial variability of this schooling species was high. Almost all specimens were collected in spring of 1993; and no significant differences in density among marshes could be detected. Striped mullet *M. cephalus* were less abundant but equally as variable in their distribution (Figure 6). No obvious patterns in mullet densities were apparent among the three created marshes. The darter goby *Gobionellus boleosoma* was abundant in the marshes, and densities were significantly lower in the 92Marsh during the first sampling period following marsh planting (Figure 6). Densities were not significantly different among the three marshes for the three following sampling periods. The bay anchovy *Anchoa mitchilli* occurred sporadically but was generally most abundant in the 92Marsh (Figure 7). Pinfish *Lagodon rhomboides* commonly occurred during spring sampling periods (Figure 7), and densities were not significantly different among the three marshes. Density patterns of these five fish species were not strongly related to marsh elevation (Figures 6 and 7), but *L. rhomboides* was generally more abundant in low-elevation edge marsh, and the ANOVA Elevation effect was significant in spring 1994.

Marsh periwinkles *Littoraria irrorata* were abundant in the 83Marsh and 87Marsh but were almost absent from the 92Marsh; densities in the 92Marsh were significantly lower than in the other two marshes for all sampling periods (Figure 7). This species was most abundant in the inner marsh samples, and the Elevation effect was significant in the ANOVAs for three of the four sampling periods.

Species richness (the number of species collected in a marsh during a sampling period) was generally similar for crustaceans and fishes (Figure 8). The number of crustacean species collected in the 92Marsh was lower than in the older marshes during the first two sampling periods. The number of fish species in the 92Marsh was only lower during the first

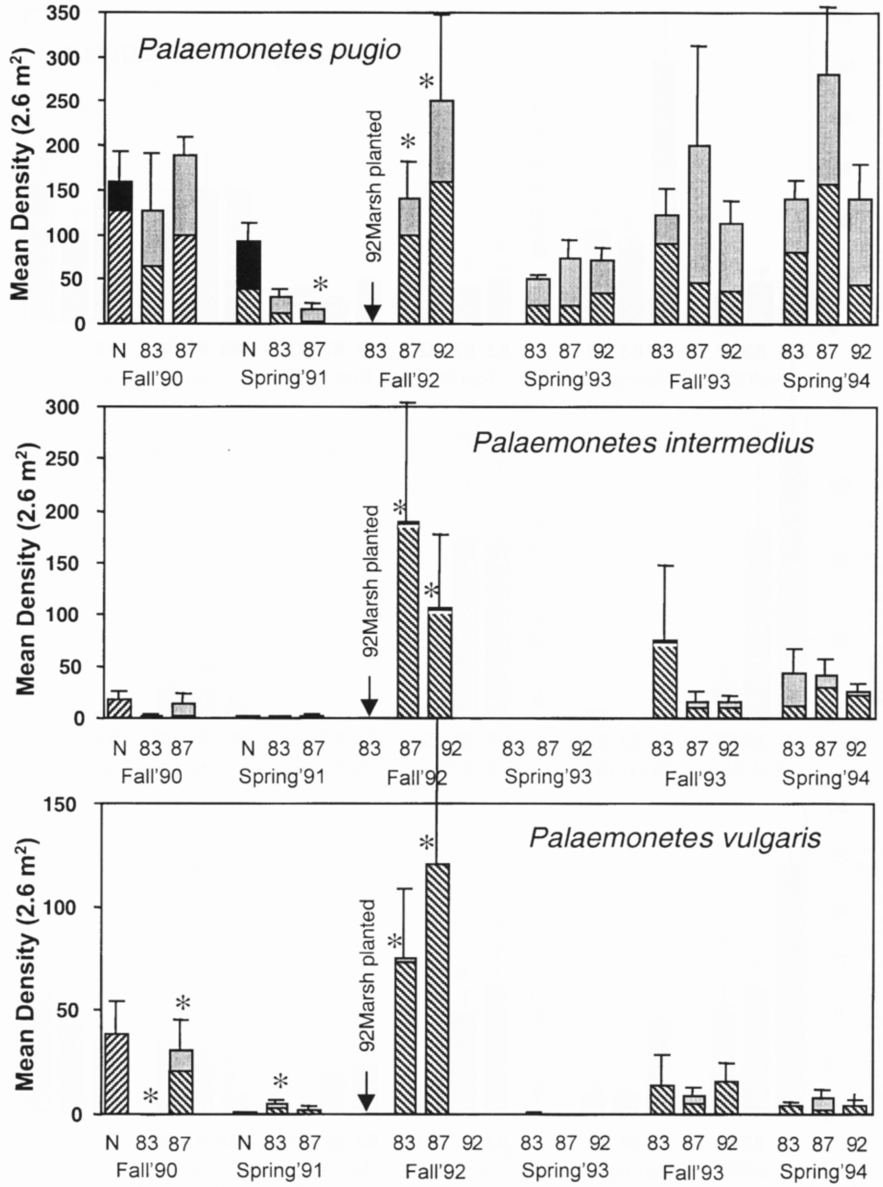


Figure 4. Mean densities (number per 2.6 m^2) of grass shrimps (error bar is 1 SE) in marshes on Pelican Spit (graphed as in Figure 3).

sampling period following marsh creation. Within one year following marsh construction, species richness of both taxa generally appeared similar among the three marshes.

Discussion

In the fall of 1992, 4 months following the planting of the 92Marsh, densities of most animals collected were significantly lower in this newly-created marsh compared with densities in the two older marshes (5 and 9 years old). This reduced utilization was consistent for the dominant natant crustaceans *Palaemonetes* spp., *Farfantepenaeus aztecus*, *Litopenaeus setiferus*, and *Callinectes sapidus* and for a dominant fish found in the marshes, *Gobionellus boleosoma*. All of these species are common inhabitants of salt marshes in the northern Gulf of Mexico (Baltz et al., 1993; Peterson and Turner, 1994; Minello, 1999). Species richness

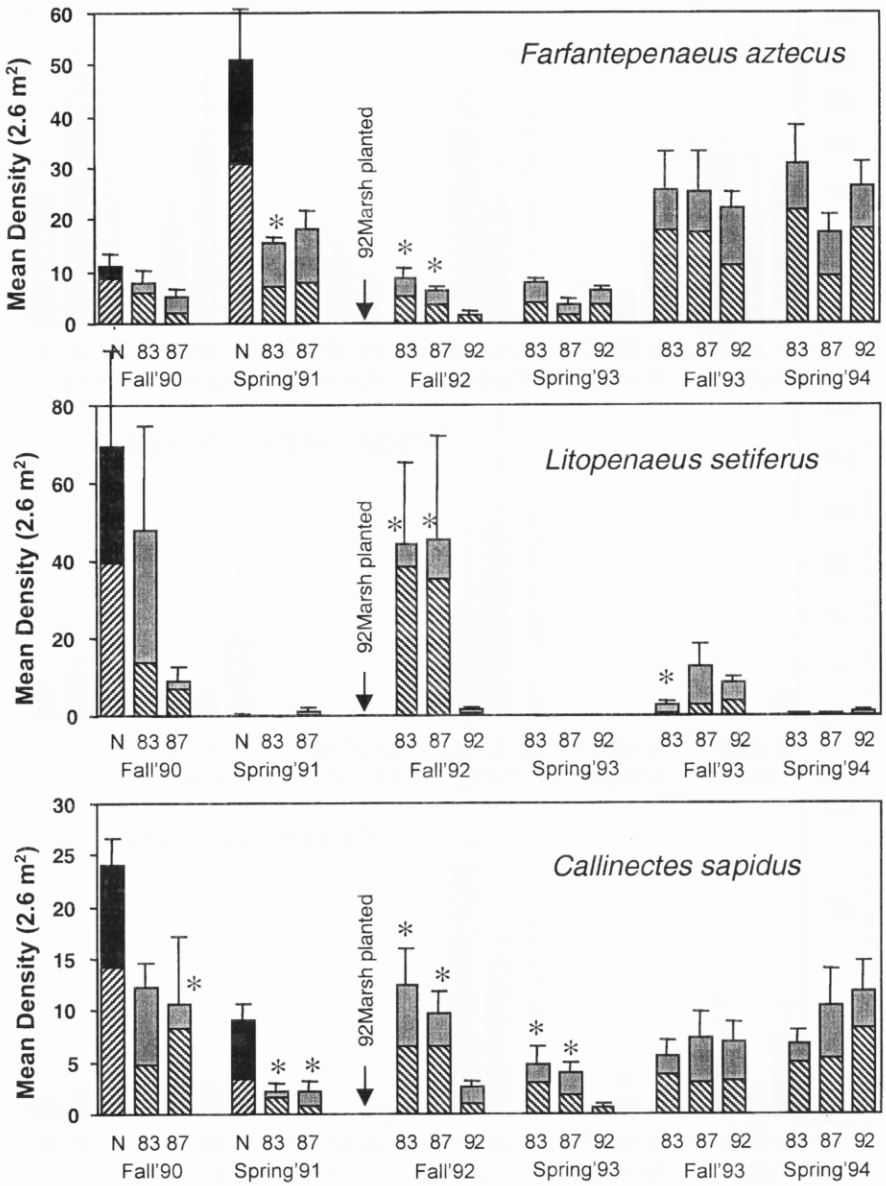


Figure 5. Mean densities (number per 2.6 m^2) of commercially-important crustaceans (error bar is 1 SE) in marshes on Pelican Spit (graphed as in Figure 3).

for both fishes and crustaceans also was lower in the 92Marsh during this first sampling period. In the spring of 1993, some nekton densities continued to be significantly lower in the 92Marsh compared with the older marshes, including *Callinectes sapidus* and *Mugil cephalus*. Mean densities of *F. aztecus*, *M. curema*, and *G. boleosoma* were also lower in the 92Marsh, but differences among the marshes were not statistically significant. Species richness of crustaceans also continued to be low in the 92Marsh.

By the second year following planting of the 92Marsh, however, nekton densities and species richness were generally similar among the marshes. Thus, density patterns in the three marshes on Pelican Spit suggest that the 92Marsh reached its maximum habitat support function for nekton in just over 1 year. By this time, densities of all abundant nekton species in

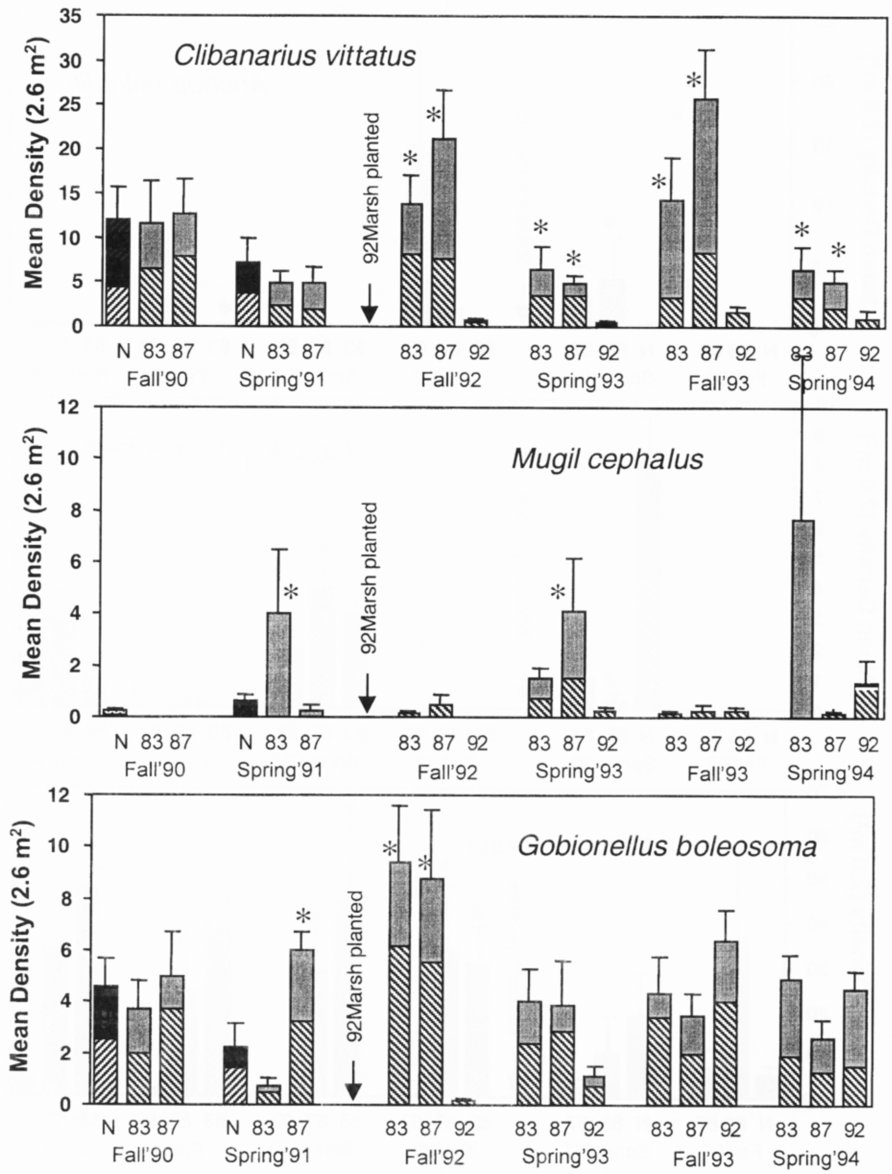


Figure 6. Mean densities (number per 2.6 m^2) of thinstripe hermit crabs and two abundant fishes (error bar is 1 SE) in marshes on Pelican Spit (graphed as in Figure 3).

the 92Marsh were comparable to or higher than those in the adjacent 10-year-old (83Marsh) and 6-year-old (87Marsh) marshes.

Densities of the thinstripe hermit crab *Clibanarius vittatus* and the marsh periwinkle *Littoraria irrorata* remained significantly lower in the 92Marsh over the entire 2-year study period. These epifaunal species have limited mobility, and annual dispersal of adult *L. irrorata* appears to occur on the scale of meters (Hamilton, 1977; Vaughn and Fisher, 1992). Recruitment to the 92Marsh for both species was probably as larvae from the plankton. Gallagher and Reid (1974) found spawning of *L. irrorata* in Tampa Bay to be temporally sporadic, and development time from fertilized eggs to free swimming veliger larvae to be less than 4 days. Thus, juvenile recruitment of this species should have been rapid, once other factors (such as *Spartina* stem density) in the marsh did not limit density. *C.*

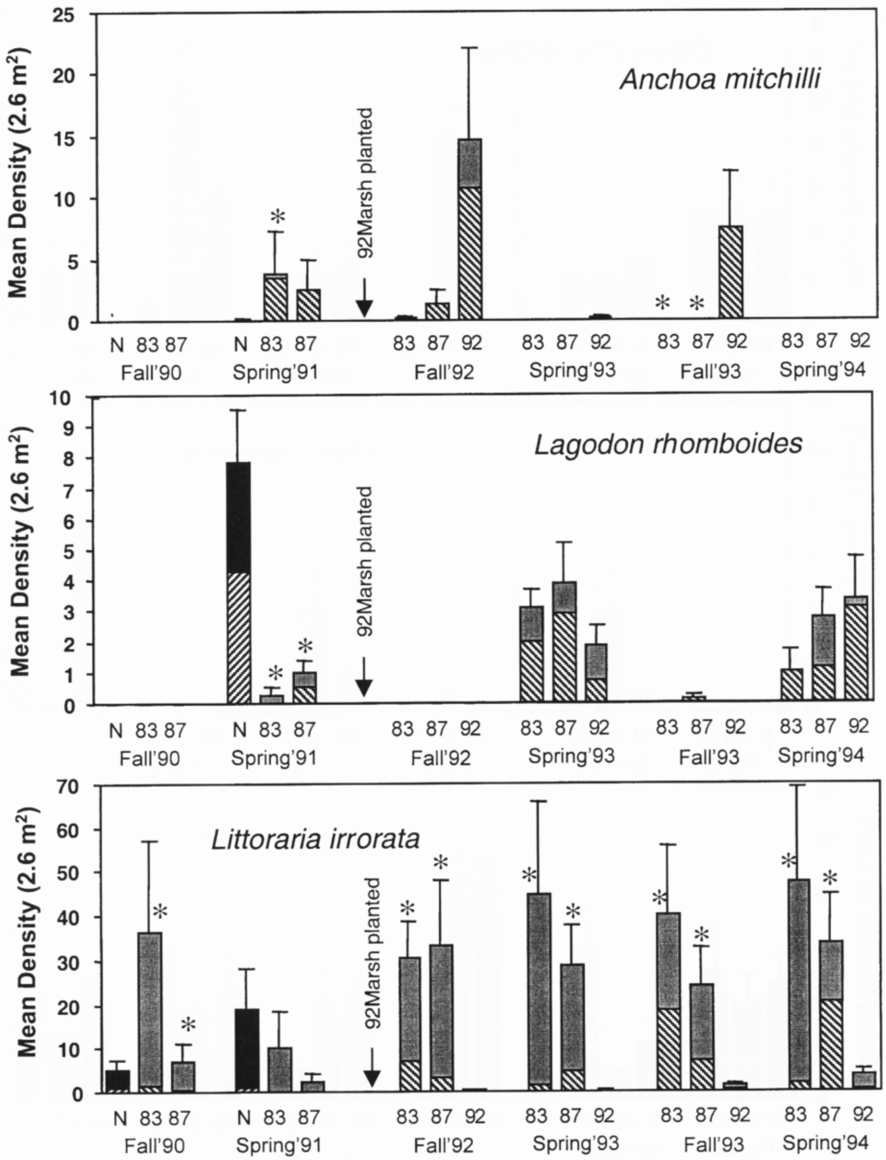


Figure 7. Mean densities (number per 2.6 m^2) of two fishes and marsh periwinkles (error bar is 1 SE) in marshes on Pelican Spit (graphed as in Figure 3).

vittatus may have been limited by differences in shell availability among the marshes, because most of the crabs inhabited *L. irrorata* shells. Poor representation by slow recruiting epifauna has also been reported for newly created marshes in the Carolinas (LaSalle et al., 1991; Levin et al., 1996).

The standing crop of *Spartina alterniflora* in the marshes was not measured routinely during this study. Stem densities were obviously lower in the 92Marsh compared with the other marshes during the first sampling period; the vegetation in the new marsh at this time was still distributed in tight clumps growing from the sprigs that were planted on 1-meter centers. In the spring of 1993, stem densities in the 92Marsh were still significantly lower than in the other marshes, but densities had already increased to about half of those in the older marshes. By the following growing season, above-ground vegetation in the three marshes

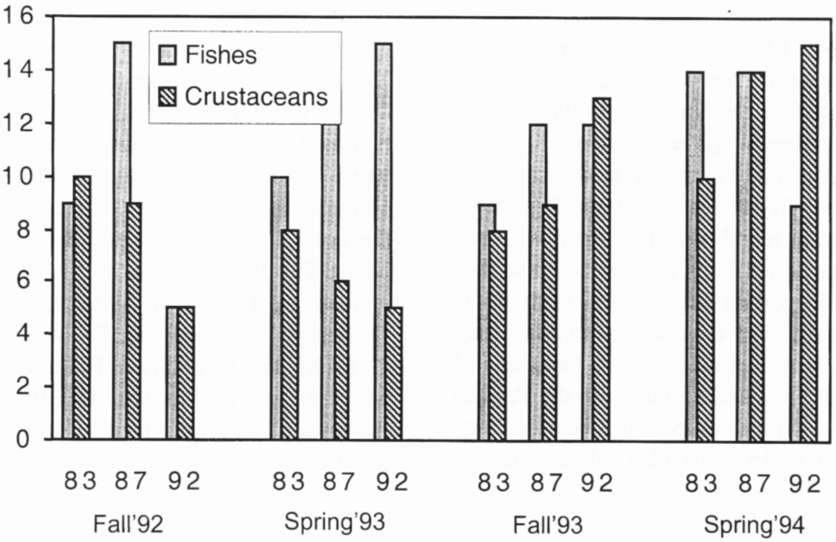


Figure 8. Species richness for fishes and crustaceans at the three created marshes on Pelican Spit. Bar heights represent the total number of species identified during a sampling period from the eight samples (20.8-m^2 area) in each marsh.

appeared comparable in stem density. From general observations, stem height, width, and overall above-ground biomass appeared higher in the 92Marsh than in the older marshes. Goldberg (1996) found that macroorganic matter (roots and rhizomes) in the upper 5 cm of sediment was lower in the 92Marsh during the first year following construction. During the second year of her study, macroorganic matter in the 92Marsh and 83Marsh were similar but lower than in the 87Marsh.

Most nekton with initially reduced densities in the 92Marsh consume benthic infauna for at least part of their diet (Laughlin, 1982; Fitzhugh and Fleeger, 1985; Gregg and Fleeger, 1998; McTigue and Zimmerman, 1998; Zimmerman et al., 2000). Infaunal populations in the three Pelican Spit marshes were dominated by the opportunistic polychaetes *Streblospio* and *Capitella*; density, biomass, and species richness in the 92Marsh were comparable to values in the older two marshes within the first year following construction (Goldberg, 1996). The rapid development of infaunal populations in the marshes, and the general lack of significant differences in densities of infauna between natural and created salt marshes along the Texas coast (Minello and Zimmerman, 1992; Minello and Webb, 1997), suggest that infaunal populations in these dredged material marshes reach parity with their natural counterparts within a few years following marsh establishment. This rapid development appears to contrast starkly with patterns observed in some marshes on the South Atlantic coast of the U.S.; Craft et al. (1999) concluded that it took 15–25 years for populations to reach parity in North Carolina salt marshes. However, variability in the natural marsh target communities may be responsible for this apparent contrast (Cammen, 1976; Sacco et al., 1994; Moy and Levin, 1991; Levin et al., 1996; Simenstad and Thom, 1996). Infaunal populations in natural marshes of the South Atlantic coast are often dominated by subsurface, deposit-feeding oligochaetes (Moy and Levin, 1991; Sacco et al., 1994; Levin et al., 1996; Posey et al., 1997; Craft et al., 1999), while populations examined in natural marshes of Texas (especially edge marsh habitats) are dominated by early colonizers and opportunistic estuarine polychaetes (Minello and Zimmerman, 1992; Levin et al., 1996; Minello and Webb, 1997; Whaley, 1997). Continual disturbance of natural marsh edge habitat may arrest infaunal communities in early successional stages (Flint and Younk, 1983; Levin, 1984; Gaston and Nasci, 1988; Levin et al., 1996). Thus, rapid development of infaunal populations observed in created marshes of Texas may be due to an early successional target community. These colonizing species are also highly productive and readily available to nekton as prey (Moy and Levin, 1991; Minello and Zimmerman, 1992; Martin and Gremare, 1997).

Nekton densities in the Pelican Spit marshes were not directly compared with those in natural marshes, because few such reference marshes occur nearby.

Data from previous work on the 83Marsh and 87Marsh (Minello and Webb, 1997) suggest that densities of most fishes and some decapod crustaceans in these created marshes on Pelican Spit are similar to densities in natural marshes of the bay system. Together, these results indicate that for many nekton species, marshes created on dredged material reach a value comparable to natural marshes in less than one year. In contrast, the value of these created salt marshes for commercially-important crustaceans such as *F. aztecus*, *L. setiferus*, and *Callinectes sapidus* may never reach parity with natural marshes. Densities of these species rapidly reached a plateau in the Pelican Spit marshes, but previous comparisons between natural and created (3 to 15 years old) salt marshes in Galveston Bay and along the Texas coast (Minello and Zimmerman, 1992; Minello and Webb, 1997) have established that densities of these species are significantly reduced in created salt marshes. For young commercially-important decapods, therefore, salt marshes created on dredged material appear to rapidly support higher densities than nonvegetated bay bottom, but these marshes do not provide the same habitat support available in natural salt marshes.

Conclusions on the relative value of created and natural marshes for estuarine nekton, however, should be tempered by the paucity of density data and the lack of other data on functions of these marsh systems for nekton. Few other quantitative comparisons of nekton densities in natural and created salt marshes have been made in the Gulf of Mexico, mainly because of problems with sampling in salt marsh vegetation (Rozas and Minello, 1997). In North Carolina, Meyer et al. (1993) generally found lower mean nekton densities (similar species to those found in Gulf) in a created marsh compared with a natural marsh, although few differences were statistically significant. Animal densities are assumed to be indicators of habitat quality, but the value of a salt marsh for estuarine nekton involves ecological relationships that may not be expressed in animal densities. Assessments of created salt marshes, therefore, should also include an examination of functional support for estuarine species. Salt marshes can provide food for enhanced growth, structure for protection from predators, and spawning sites for enhanced reproduction, and these functional values are not necessarily reflected in utilization patterns. For example, gut analyses indicated that diets of *Fundulus* in a North Carolina created salt marsh contained less detritus and were nutritionally superior to diets of fish in adjacent natural marshes (Moy and Levin, 1991).

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